CSI RD&D – Solaria HQ System Performance Report

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This report is generated as part of Solaria's performance reporting obligation outlined in "Task 5: Deliverables" of the contract between Solaria Corp. and Itron Inc.

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1 Contents

2 Background

This project is supported with assistance from the California Solar Initiative (CSI) Research, Development, Demonstration, and Deployment Program (RD&D). The purpose of this program is to help achieve the goal of creating a vibrant solar industry. This program makes investments to fund solar research and demonstration projects that will measurably reduce the cost and accelerate the installation of solar and other distributed technologies that could employ solar for generation, storage, or that could reduce the use of natural gas. The goal of this project is to demonstrate the financial and technical viability of Solaria's technology.

3 Introduction

Solaria, a California Corporation, has developed a photovoltaic module that uses 50-67% less silicon than the other silicon modules and are designed to not have any compromises in performance or reliability. Solaria modules are the first flat plate PV module to use optical concentration and the first low-concentration module to receive UL and IEC certification. Solaria's module is optimized for large-scale commercial and utility tracking applications.

The goal of this CSI RD&D project is to perform detailed analysis and reporting on the performance of Solaria low-concentrating photovoltaic installations that incorporate innovations to reduce costs, increase reliability, and improve system production and efficiency. Solaria is using CSI RD&D funds to support installing and operating PV test systems to demonstrate that the technology is financeable. The project will also provide performance and reliability data of Solaria's products on different tracking systems totaling 350 kWp_{dc} for two installations of which 240 kWp_{dc} will be installed at Alameda County Santa Rita Jail located in Dublin, CA and 110 kWp_{dc} will be installed at Solaria manufacturing facility located in Fremont, CA.

The purpose of this quarterly report is to demonstrate the performance and commercial viability of Solaria's technology. The cost and performance metrics covered by this report include those of operational efficiency, maintenance and repair, operating costs and electricity production. The systems covered by this report are the Horizontal and Azimuth tracking systems installed at Solaria's headquarters with a total system size of 110kW. Future reports will include the performance analysis of the 240kW_{dc} system at Santa Rita Jail.

4 Energy Production

This section includes the various energy production metrics detailed in Task 5 deliverables

4.1 System Layout and Module Evaluation

Shown below is the layout of the Solaria HQ system. The total system size is 110kWp$_{dc}$ with the Horizontal Axis tracker system being 58.1 kWp$_{dc}$ and the azimuth tracker system being 52.9kWp$_{dc}$. As shown the system comprises of 6 rows of horizontal axis trackers and 12 azimuth trackers.

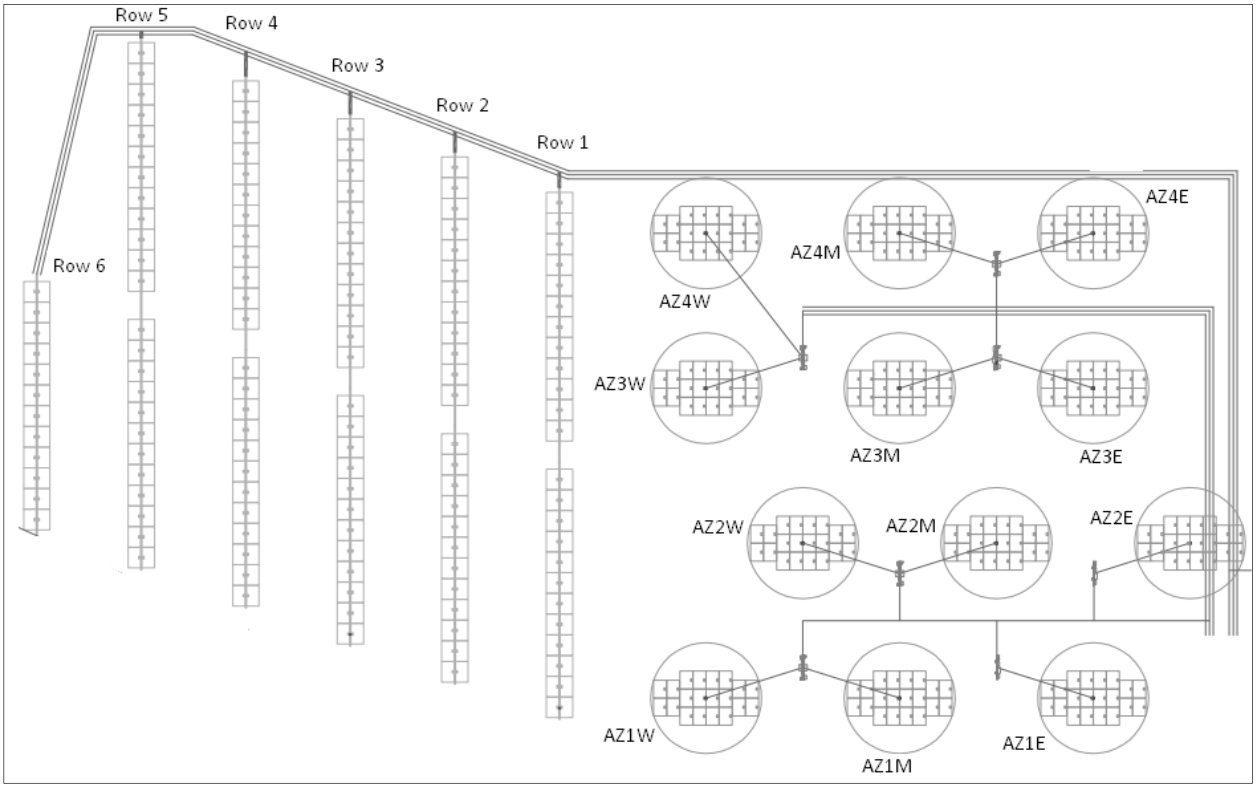

Figure 1: Solaria HQ Horizontal and Azimuth systems Layout

The individual module types and inverter types used for each string are shown in the table below. Different generations of Solaria modules that include Solaria 210W, 220W, 230W, 260W, Framed and Frameless have been used. The SMA 10kW and 5kW inverters have been used for individual strings. Shown in the Table 2.1 are the Solaria module characteristics.

System	Module	Inverter Manufacturer	Inverter Model
Row 1	Solaria 220/210 Framed	SMA Solar Technology AG	SB10000TL-US
Row 2	Solaria 230 Frameless	SMA America	SB5000US
Row 3	Solaria 230 Framed	SMA Solar Technology AG	SB10000TL-US
Row 4	Solaria 220/230 Frameless	SMA Solar Technology AG	SB10000TL-US
Row 5	Solaria 210/220/230 Frameless	SMA Solar Technology AG	SB10000TL-US
Row 6	Solaria 220/230 Frameless	SMA America	SB5000US
AZ1W	Solaria 220 Frameless	SMA America	SB5000US
AZ1M	Solaria 210 Frameless	SMA America	SB5000US
AZ1E	Solaria 210/220 Frameless	SMA America	SB5000US
AZ2W	Solaria 210 Frameless	SMA America	SB5000US
AZ2M	Solaria 210 Frameless	SMA America	SB5000US
AZ2E	Solaria 260 Frameless	SMA America	SB5000US
AZ3W	Solaria 220 Frameless	SMA America	SB5000US
AZ3M	Solaria 220 Frameless	SMA America	SB5000US
AZ3E	Solaria 220 Frameless	SMA America	SB5000US
AZ4W	Solaria 210/220 Frameless	SMA America	SB5000US
AZ4M	Solaria 230 Frameless	SMA America	SB5000US
AZ4E	Solaria 210 Frameless	SMA America	SB5000US

Table 1: Modules and Inverters used for Solaria HQ plant

Peak Power, Pmax (Watts)*	210	220	230	260
Open Circuit Voltage, Voc (V)	43.53	43.32	43.20	44.308
Short Circuit Current, Isc (A)	7.125	7.59	7.59	8.85
Voltage at Pmax (V)	37.69	35.01	34.13	35.45
Current at Pmax (A)	5.75	6.86	7.10	8.28
Max Series Fuse Rating (A)	15	15	15	15
Max System Voltage (V)	US600/IEC1000	US600/IEC1000	US600/IEC1000	US600/IEC1001

Table 2: Module Characteristics

**The different module ratings are due to cell bins.*

4.2 Operating temperatures

This section describes the operating temperatures of modules on azimuth and horizontal trackers. It is important to understand the thermal behavior of the module as the cell efficiency is inversely related to the operating temperatures. The higher operating temperatures for azimuth tracker in the winter months can be explained by the higher irradiance captured by the azimuth tracker during that period.

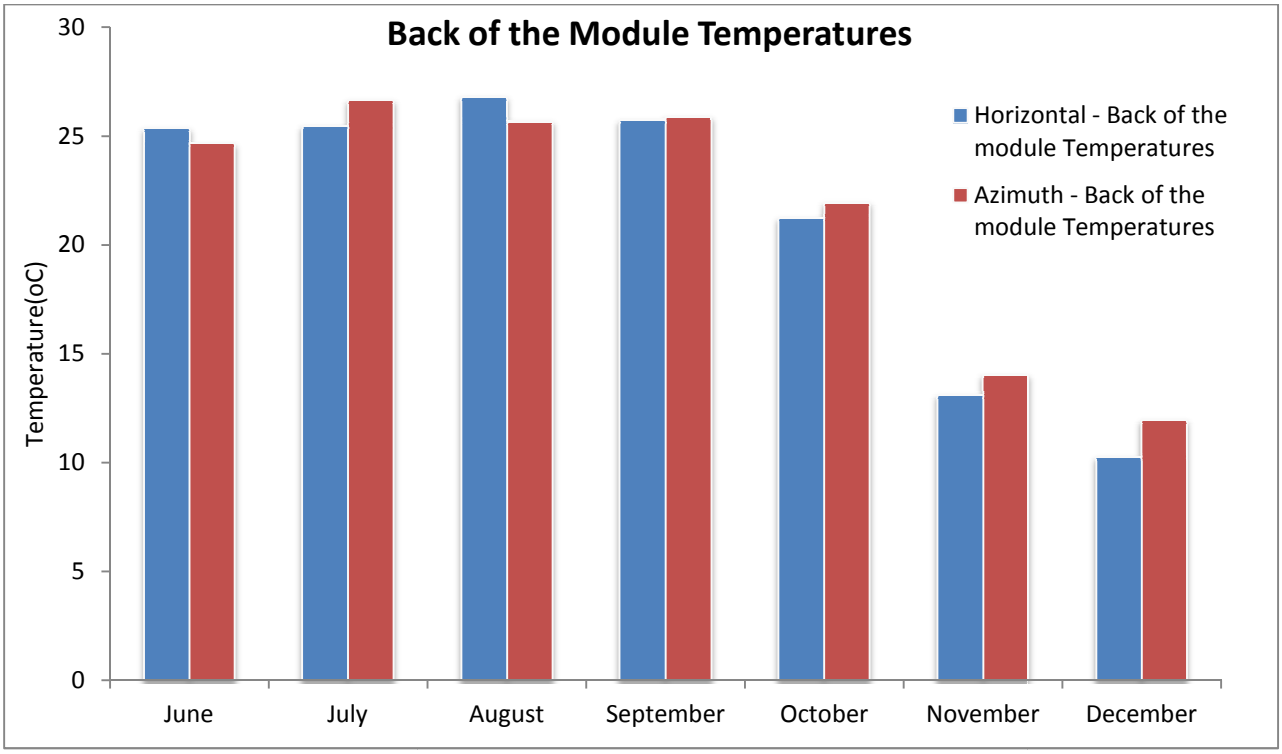

Figure 2: Operating Temperatures – Horizontal and Azimuth Tracking Systems

Month	Horizontal-Module temperature [°C]	Azimuth-Module temperature [°C]
June	25.3	24.7
July	25.5	26.6
August	26.8	25.7
September	25.7	25.9
October	21.2	21.9
November	13.1	14.0
December	10.2	11.9

Table 3: Operating Temperatures Summary

4.3 AC and DC Energy Production

This section shows the AC and DC energy production of both azimuth and horizontal systems. It can be seen that the azimuth system performs better than the horizontal system. The higher performance of the azimuth tracker can be explained by the lower angles of incidence of the beam component of the light.

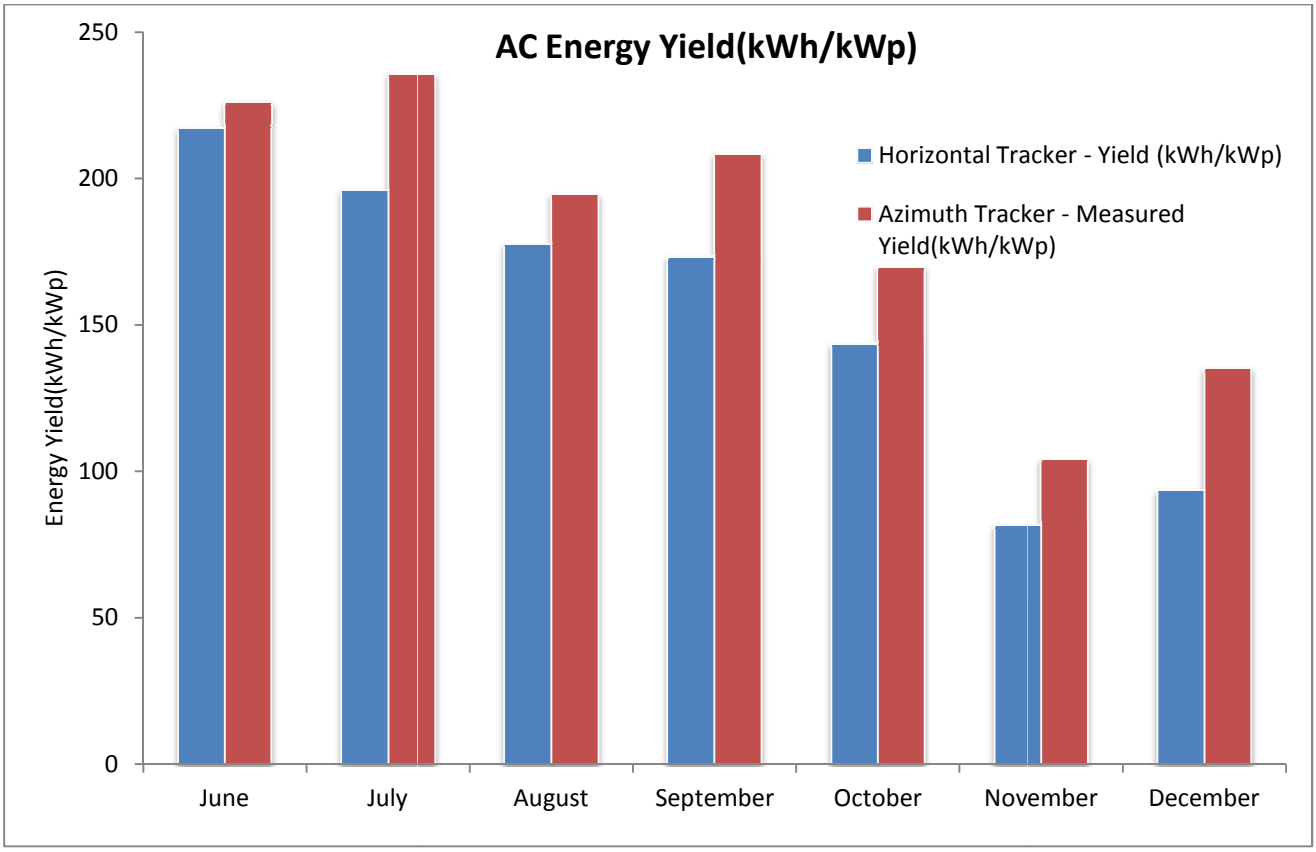

Figure 3: AC Power Production – Horizontal and Azimuth Tracking System

Month	Horizontal - Energy Yield(kWh/kWp)	Azimuth - Energy Yield(kWh/kWp)
June	217.14	225.99
July	195.94	235.75
August	177.54	194.53
September	173.25	208.27
October	143.47	169.85
November	81.56	104.15
December	93.57	135.10
Total	1082.46	1273.64

Table 4: Energy Generation – Summary

The DC Power production for the AZ4M tracker, on which high accuracy shunt resistors have been installed, is shown below.

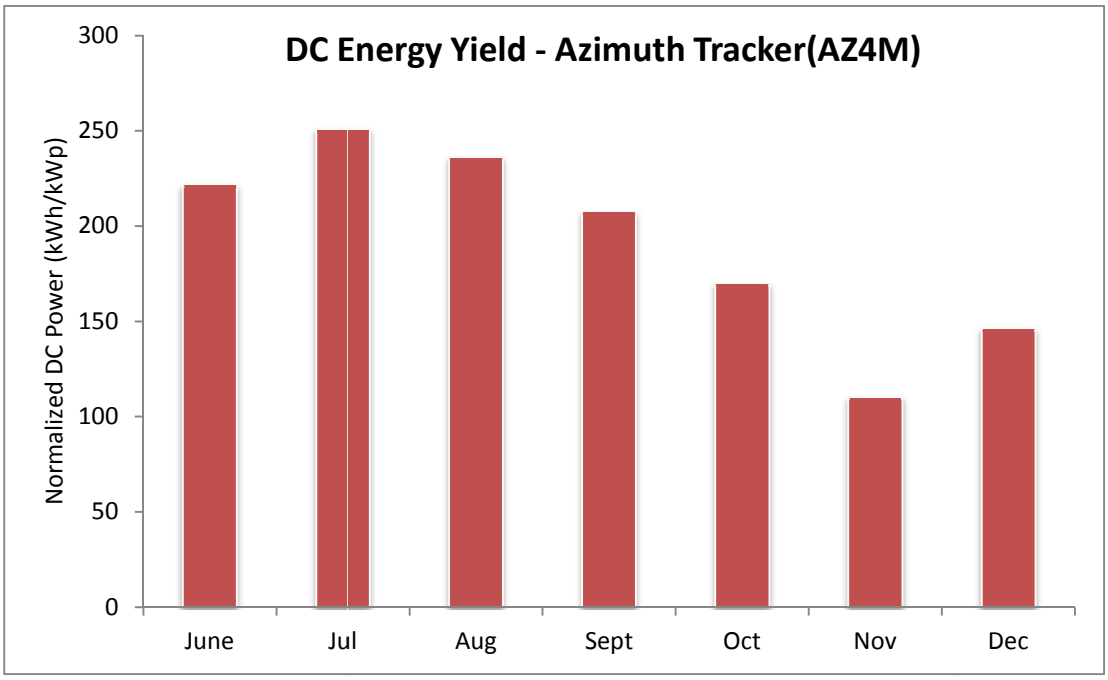

Figure 4: DC Power Production (AZ4M)

4.4 Correlate actual energy production with simulations

Simulations have been performed for strings that were equipped with the required instrumentation (i.e. pyranometer) to measure plane of array irradiance (POA) and thermocouples to measure back of the module temperatures. The measured POA and back of the module temperatures were then used to weather normalize the expected performance. An in-house model was used for the expected energy simulations. This model is also currently being used for energy yield simulations.

Row 3 of the horizontal tracking system and AZ4M of azimuth tracking system fit the criteria of having sufficient monitoring in place and thus were selected for the Actual vs. Expected energy comparisons. The actual vs. simulation comparison starts from August (limited due to Global Irradiance data). The AZ4M tracker consists of 2 strings of 10 230W modules and shown below is the Actual vs. Expected Energy chart for the same. The Performance Index (Actual Energy/Expected Energy) was found to be 102.4%.

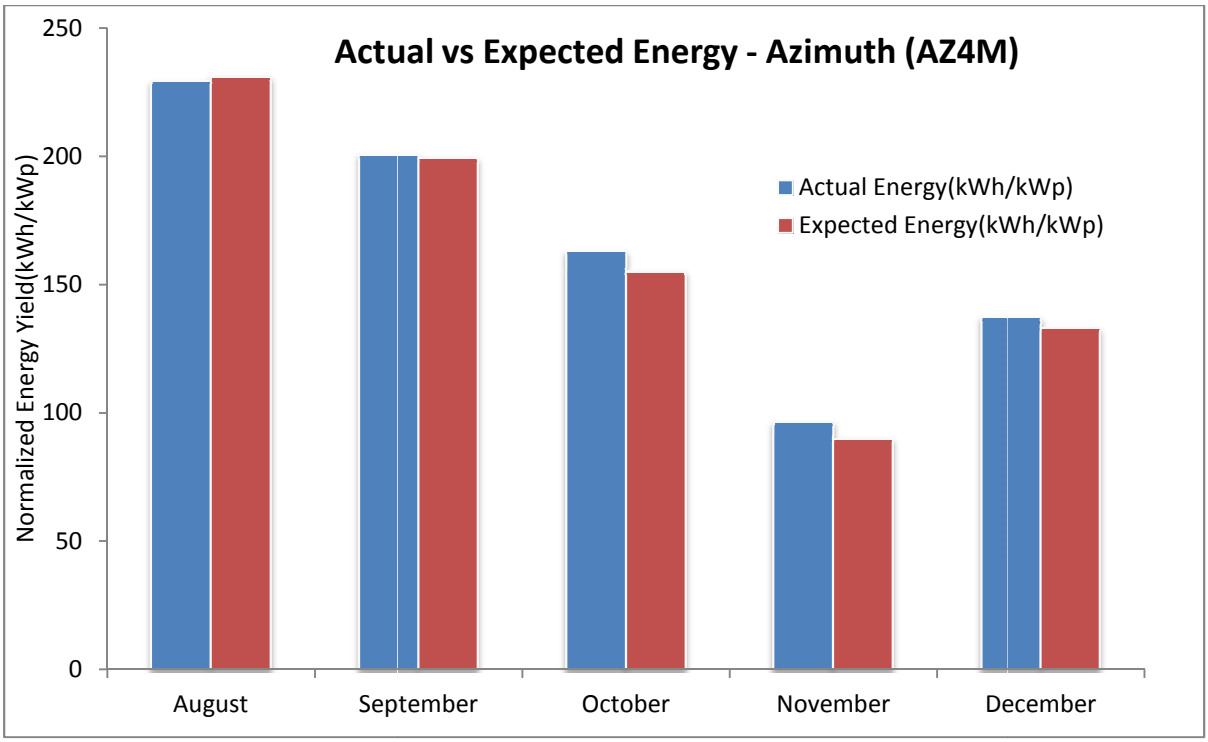

Figure 5: Actual vs. Expected Energy (AZ4M)

Month	Actual Energy(kWh/kWp)	Expected Energy(kWh/kWp)
August	229	231
September	201	199
October	163	155
November	96	90
December	137	133
Total	**826**	**808**

Table 5: Actual vs. Expected Energy Summary - AZ4M

Shown here is the Actual vs. Expected energy comparison of the row 3 of the horizontal axis tracker. Row 3 consists of 4 strings of 12 230W modules. The system outperformed expectations for all months except August. The Performance Index was found to be 102.3% which is very close to what was observed for the azimuth tracker indicating a systematic bias. One potential reason for this bias is the irradiance transposition model which seems to overestimate the diffuse content which consequently is leading to the under prediction.

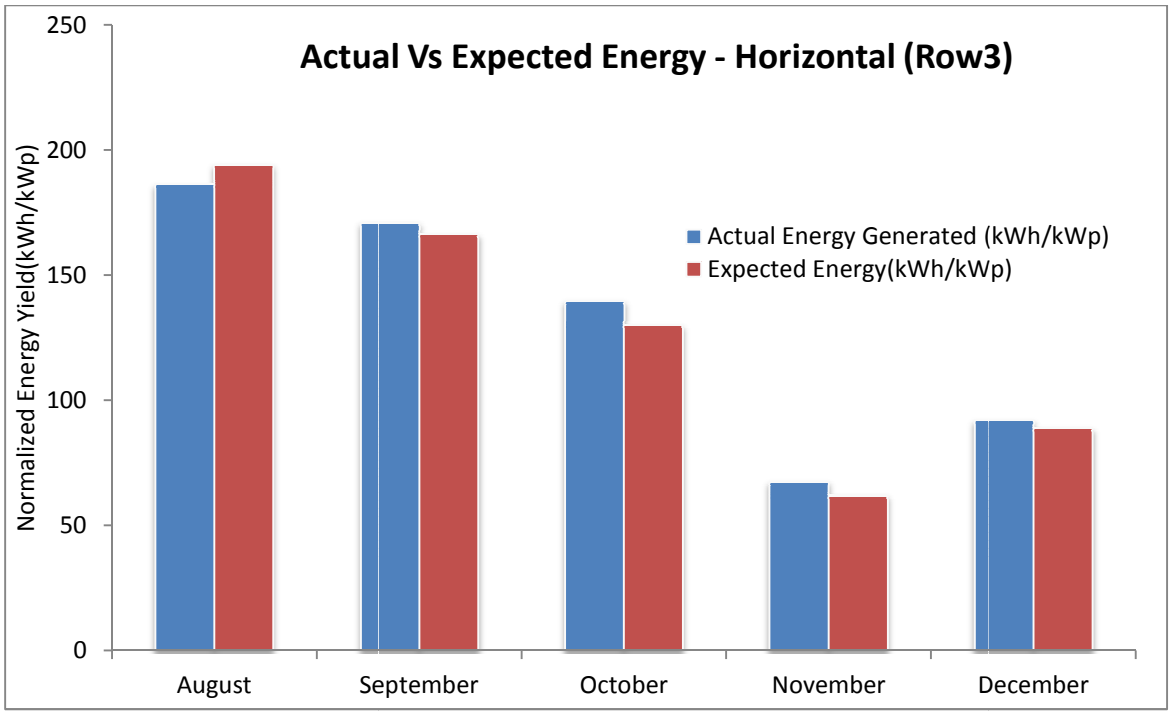

Figure 6: Actual vs. Expected Energy - Row 3

Month	Actual Energy(kWh/kWp)	Expected Energy(kWh/kWp)
August	186	194
September	171	166
October	140	130
November	67	62
December	92	89
Total	**656**	**641**

Table 6: Actual vs. Expected Energy Summary - Row 3

4.5 Weather summary

Shown in this section is the measured onsite weather data compared to the historical weather data. As shown here the measured irradiance seemed to be higher for most months. The Perez model was used to transpose the TMY Global Horizontal Irradiance to Plane of array Irradiance.

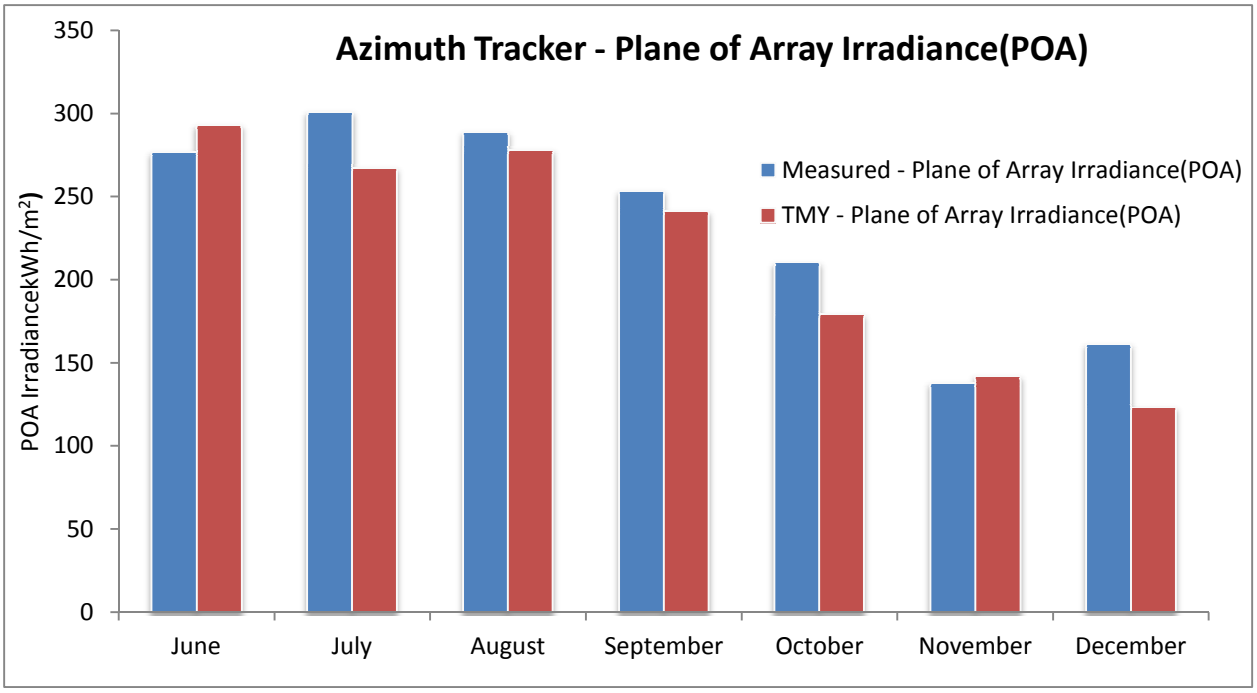

Figure 7: Plane of Array Irradiance - Azimuth Tracker

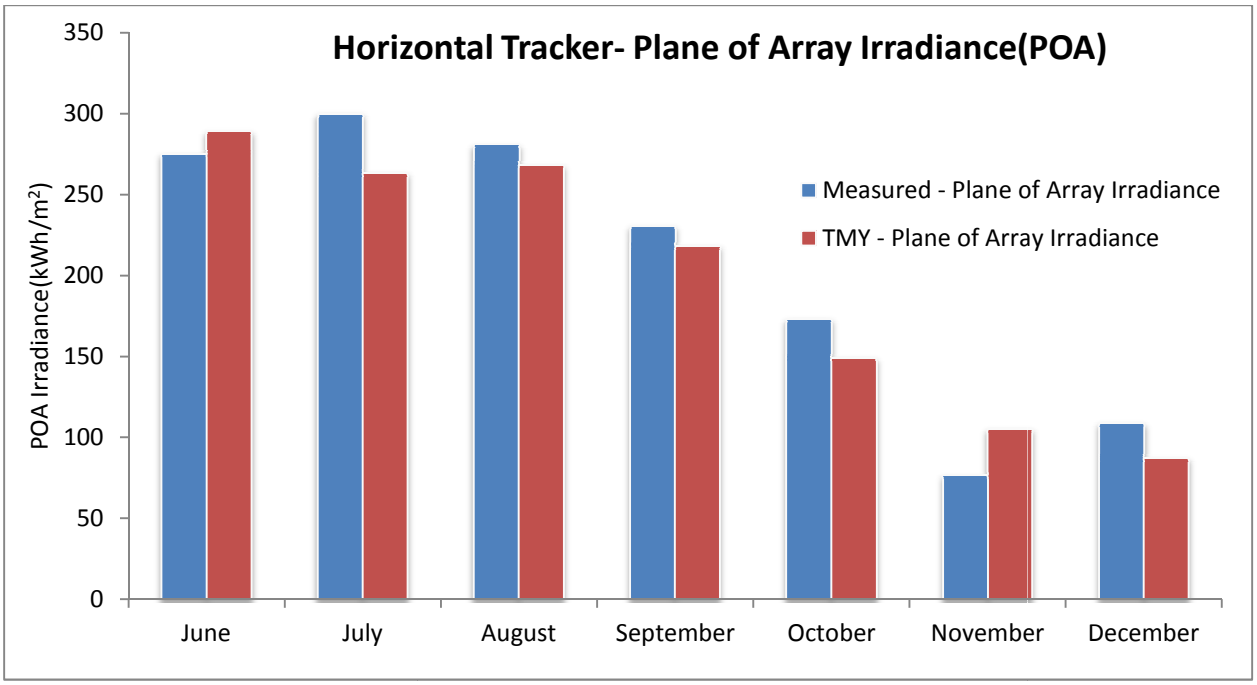

Figure 8: Plane of Array Irradiance - Horizontal Tracker

The ambient temperatures were measured to be lower than the TMY data. The measured wind speeds were also significantly lower than the TMY data. Further analysis is being done to understand the significant difference in wind speeds.

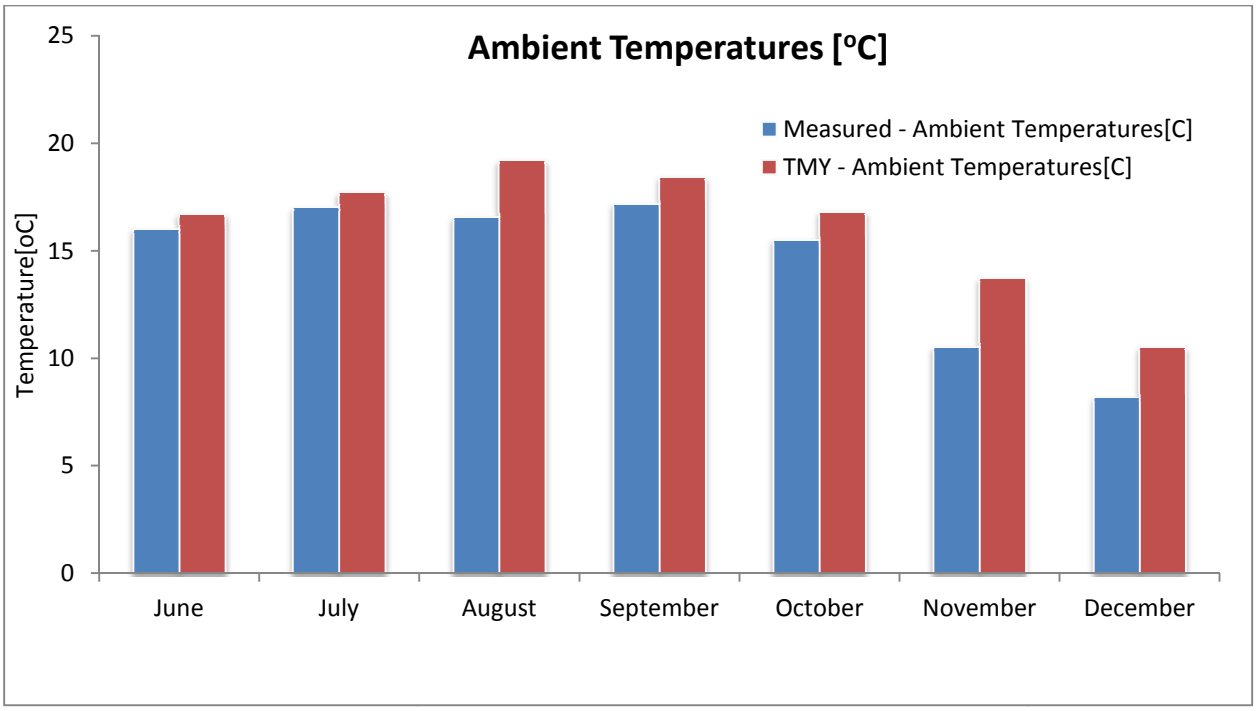

Figure 9: Ambient Temperature

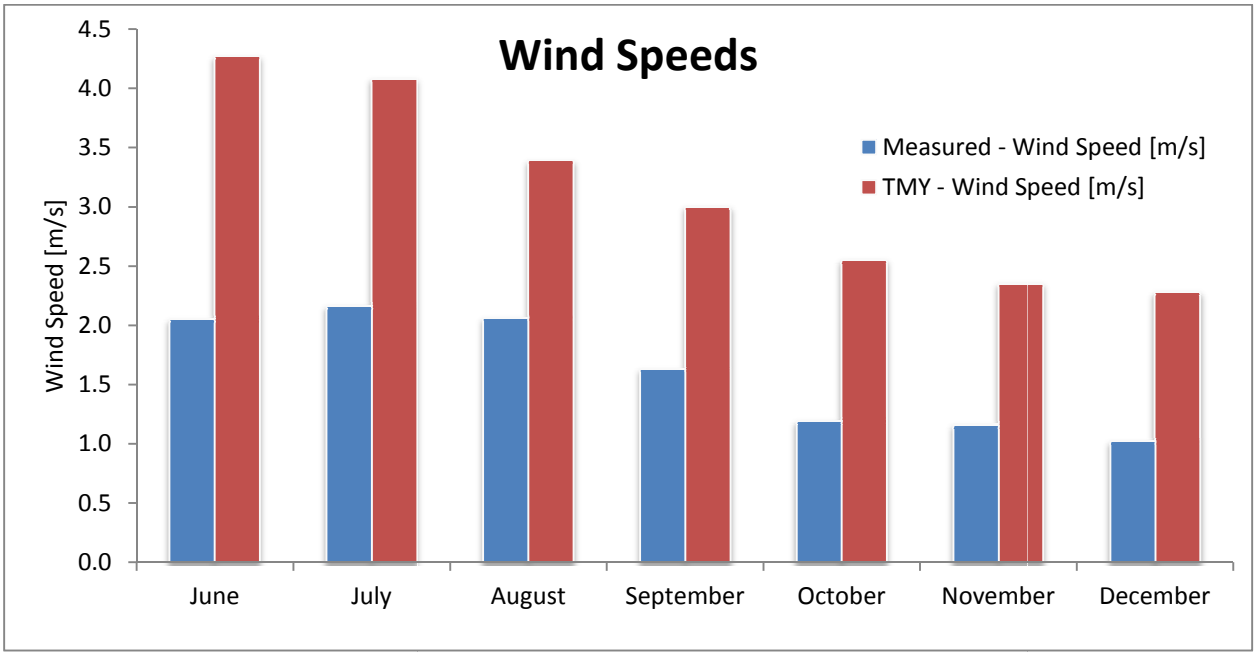

Figure 10: Wind Speed

Month	Measured-Ambient temperature [°C]	Measured - Wind speed [m/s]	Horizontal-Measured POA[kWh/m²]	Azimuth-Measured POA [kWh/m²]
June	16.0	2.1	275	277
July	17.0	2.2	300	301
August	16.6	2.1	281	289
September	17.2	1.6	230	253
October	15.5	1.2	173	210
November	10.5	1.2	76	138
December	8.2	1.0	109	161

Table 7: Measured Weather Summary

Month	TMY - Ambient Temperature [°C]	TMY - Wind speed[m/s]	Horizontal-TMY POA[kWh/m²]	Azimuth-TMY POA[kWh/m²]
June	16.7	4.3	289	293
July	17.7	4.1	263	267
August	19.2	3.4	268	278
September	18.4	3.0	218	241
October	16.8	2.6	149	179
November	13.7	2.4	105	142
December	10.5	2.3	87	123

Table 8: TMY Weather Summary

4.6 System availability

The system availability for the period of interest was 100%.

5 Operating Results

Installation costs for the Santa Rita Jail (SRJ) system are provided below. Solaria was able to reduce installation costs for the SRJ system based on lessons learnt from the Installation at Solaria HQ. Solaria HQ System costs were above average relative to SRJ due to the research and development nature of the HQ project. Shared below, the Santa Rita Jail System costs provide a price point where Solaria continues to drive down system prices and the Installed Cost per Watt.

SRJ PV System Costs	Costs	
System Installation services	$	510,000.00
Modules	$	191,760.00
Trackers	$	121,220.00
Inverters	$	150,000.00
Installed cost per capacity($/Wac)	$	4.05

Table 9: Santa Rita Jail (240kW) PV System Costs

Solaria HQ Maintenance Costs	Costs	
PV System Maintenance	$	1,453.00
Array cleaning	$	540.00
Landscape maintenance	$	2,100.00
Total Maintenance costs*	$	4,093.00

Table 10: Solaria HQ Maintenance Costs

**Operating and Maintenance costs listed above reflect extensive landscaping work as mandated by the city of Fremont and various R&D activities that would not typically be undertaken on a commercial project*.

6 Module Degradation

6.1 Module cleaning study

The goal of this study was to quantify the impact of soiling on Solaria modules. The study covered the performance data of AZ4M system installed on Solaria HQ during the dry season which is generally the period between the last day of spring rainfall and first rainfall after the summer. For the Fremont region in the year of 2011, it was the period between June 29th and September 7th (with scheduled wash on Sep 8th and first rainfall on Sep 9th). Performance Index which is defined as the ratio of actual energy to expected energy was the chosen metric for this study. The soiling rates of Solaria and flat plate PV reference modules have been quantified in this study. It can be seen from the plot below that the soiling rate of Solaria's system is comparable to that of the reference system.

Figure 11: Dry Season Performance Drop

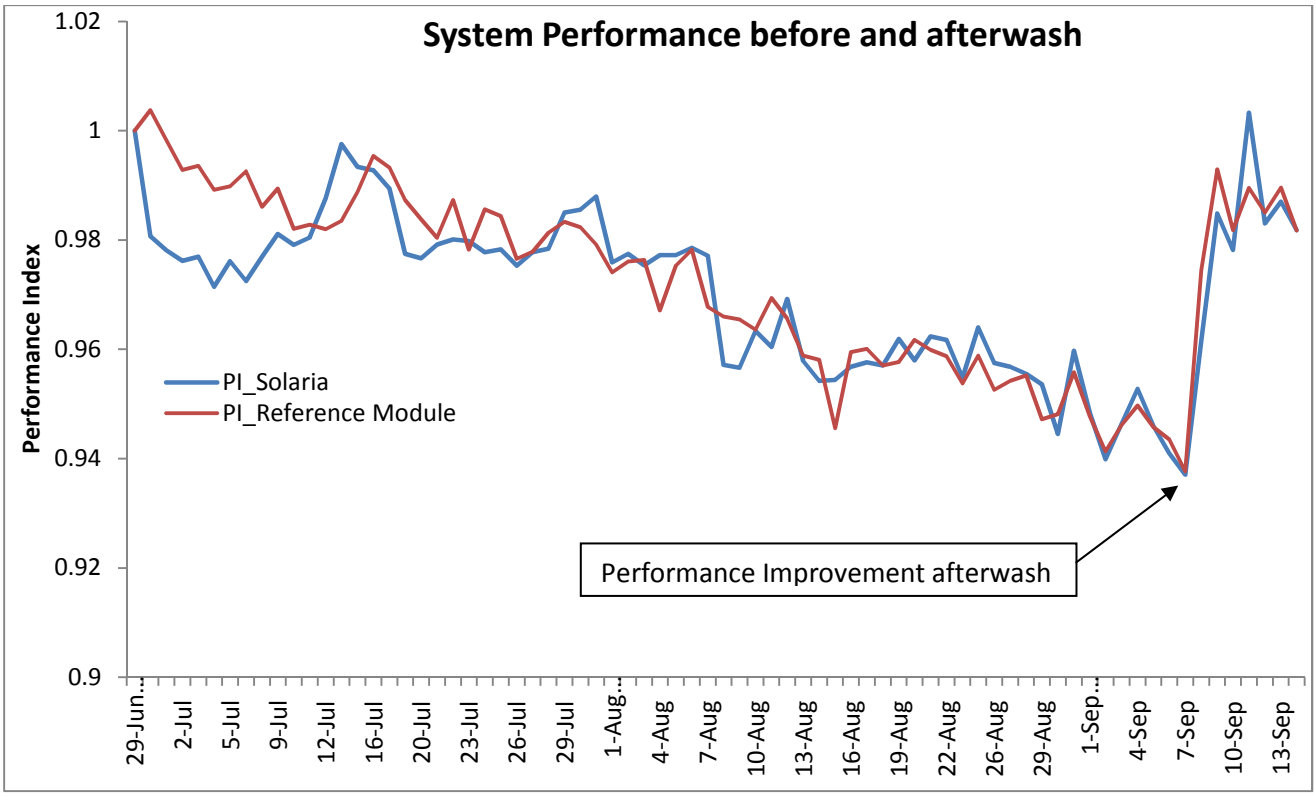

Figure 12: Performance Improvement afterwash

System	Soiling Rate	Dry season Loss
Solaria	0.08%	5.36%
Reference	0.09%	6.03%

Table 11: Module cleaning analysis results

6.2 Degradation measurement

As shown in the previous section the performance improves immediately after the wash indicating the degradation was only due to the soiling. The difference between Performance Index at t=0 and immediately after wash is 0.7% which is within the measurement uncertainty. Hence it can be concluded that there was no measurable degradation in module performance due to factors other than soiling.

7 Long Term Reliability

This section documents any reliability issues observed during the period of operation. The actual vs. expected energy performance comparisons and visual inspection of modules were done to identify any anomalies and discrepancies in the module performance. The actual vs. expected energy performance analysis do not point to any reliability issues. The results of the visual inspection are presented below.

7.1 Results of visual inspection of modules on the test systems

Shown here are the results of visual inspection of a string of modules on Row 3.

Module ID	Dimensional Check	Abnormal Soiling Pattern	Cable Connection breakage	Edge Delamination
HYCD190233291	No Change	None	None	None
HYCD190233287	No Change	None	None	None
HYCD190233282	No Change	None	None	None
HYCD190233294	No Change	None	None	None
HYCD190233301	No Change	None	None	None
HYCD190233219	No Change	None	None	None
HYCD190233220	No Change	None	None	None
HYCD190233255	No Change	None	None	None
HYCD190233474	No Change	None	None	None
HYCD190233487	No Change	None	None	None
HYCD190233484	No Change	None	None	None
HYCD190233451	No Change	None	None	None

Table 12: Results of Visual Inspection

7.2 Description of any reliability issues or concerns

Based on the visual inspection of the modules and Actual vs. Expected energy comparisons we can say that there were no reliability issues for the period of interest.

7.3 Maintenance, repairs, cleaning, or system abnormalities during the month.

Regular maintenance work is performed on the systems to ensure proper operation. A few of the activities are shown in the table below to illustrate the nature of the maintenance work done over the period of interest.

Event Date	Asset	Event Description
6/27/2011	Row5	Replaced Draker DC board to monitor stings on row 5
6/27/2011	Horizontal Pyranometer	Moved Pyranometer from North end of Horizontal row 3 from North end to Middle
6/27/2011	AZ4M Pyranometer	Moved support lower for pyranometer to avoid potential for damage to module back sheet by flexing.
7/6/2011	Inverter	During commissioning a thermal event inside the SMA SB10000TL (SN 2001586055) was noticed. Inverter was removed and replaced with a new inverter (SN 2001587028).
7/20/2011	AZ1E Tracker	Tracker stopped and inverter shut off to retrofit new rails onto tracker.
9/20/2011	AZ Trackers, Entire system	All system was set to South on at a time the rotation sensors were spun around 180 degrees, south was reset on the tracker then the tracker was set back to normal tracking mode.
9/20/2011	Thermocouples #6&#8 on HT Row 3	Thermocouples removed and cleaned off, then epoxy in place
9/20/2011	Horizontal Tracker	Tracker set to stow to mechanically adjust rows to obtain row planarity
1/26/2012	Horizontal Tracker	New PLC installed on HT motor controller, took approx 3 hours to get functioning properly.
2/9/2012	Horizontal Tracker	Clock was off by 7 min, adjusted and calibration cycle

Table 13: Onsite Maintenance Activities

8 Conclusions

For the given period of observation there was no measureable module degradation. Module degradation studies will be continued into the future and the results for a longer period of observation will be presented in future reports. The measured performance is compared with modeled performance and the results showed a good correlation between the measured and modeled values but the performance models slightly underestimated the system performance. The accuracy of the prediction model will be further improved by using the measured plane of array irradiance directly instead of using transposition models. No reliability issues were identified with the modules based on the visual inspection and Actual Vs Expected comparisons. The operational and maintenance costs were observed to be on par with industry standards. The system availability was 100% as there were no unplanned

outages. A soiling analysis was conducted and the results show that the Solaria modules do soil at rates comparable to standard flat plate PV modules.